AIR MANAGING SYSTEMS AND METHODS FOR GAS DEPOLARIZED POWER SUPPLIES UTILIZING A DIAPHRAGM

Related Applications

The following patent applications for related subject matter,

"CYLINDRICAL METAL-AIR BATTERY WITH A CYLINDRICAL PERIPHERAL AIR CATHODE" (Serial No. 09/215,820); 6,274,261

"AIR MOVER FOR A METAL-AIR BATTERY UTILIZING A VARIABLE VOLUME ENCLOSURE" (Serial No. 09/216,118); patent 6,436,564

"AIR DELIVERY SYSTEM WITH VOLUME-CHANGEABLE PLENUM OF METAL-AIR BATTERY" (Serial No. 09/216,660); and 6,846,841

"AIR MANAGER SYSTEMS FOR METAL-AIR BATTERIES UTILIZING A DIAPHRAGM OR BELLOWS" (Serial No. 09/216,026) 6,475,658

are incorporated herein by reference.

Technical Field

The present invention relates to gas depolarized electrochemical power sources, such as metal-air batteries or fuel cells of the type that are supplied with reactive gas by an active air moving device, and more particularly relates to

an air mover mechanism that utilizes a diaphragm or bellows to move air in and out of one or more air openings or to move air from an inlet to an outlet.

Background of the Invention

Generally described, a metal-air cell, such as a zinc-air cell, uses one or more air permeable cathodes separated from a metallic zinc anode by an aqueous electrolyte. During operation of the cell, oxygen from the ambient air is converted at the one or more cathodes to produce hydroxide ions. The metallic zinc anode is then oxidized by the hydroxide ions. Water and electrons are released in this electrochemical reaction to provide electrical power.

Initially, metal-air cells found limited commercial use in devices, such as hearing aids, which required a low level of power. In these cells, the air openings which admitted air to the air cathode were so small that the cells could operate for some time without flooding or drying out as a result of the typical difference between the outside relative humidity and the water vapor pressure within the cell. However, the power output of such cells was too low to operate devices such as camcorders, cellular phones, or laptop computers. Furthermore, enlarging the air openings of a typical "button cell" was not practical because it would lead to premature failure as a result of flooding or drying out.

In order to increase the power output of metal-air cells so that they could be used to operate devices such as camcorders, cellular phones, or laptop computers, air managers were developed with a view to providing a flow of reactive air to the air cathodes of one or more metal-air cells while isolating the cells from environmental air and humidity when no output is required. As compared to conventional electrochemical power sources, metal-air cells containing air managers provide relatively high power output and long lifetime with relatively low weight. These advantages are due in part to the fact that metal-air cells utilize oxygen from the ambient air as the reactant in the electrochemical process as opposed to a heavier material such as a metal or a metallic composition. Examples of air managers are shown in U.S. Patents 4,913,983, 5,356,729, 5,691,074 and 5,919,582.

A disadvantage of most air managers, however, is that they utilize an air moving device, typically a fan or an air pump, that occupies space that could otherwise be used for battery chemistry to prolong the life of the battery. This loss of space presents a particular challenge in attempts to provide a practical metal-air cell in small enclosures such as the "AA" cylindrical size now used as a standard in many electronic devices.

In addition to being bulky, air moving devices used in metal-air batteries also consume energy stored in the metal-air cells that might otherwise be delivered as power output to a load. Complicated electronics for controlling an air manager can increase this use of stored energy; in addition they add considerable

expense. Also, as most air moving devices used in metal-air cells distribute air to a cathode plenum at low pressure, a flow path must be defined passing over all regions of the cathode surface to evenly distribute air to the entire cathode surface. Thus, the function of bringing in make up air and the function of mixing and distributing air within the battery have been separate. A further disadvantage of fans used as air moving devices in metal-air cells is that they may create noise at a level disruptive to users of devices such as cellular telephones.

As a result, while a key advantage of metal-air cells is their high energy density resulting from the low weight of the air electrode, this advantage has been compromised by the cost, space and power required for an effective air manager, and the noise it may produce. In addition, the operation of the air manager may not be necessary for all levels of power draw from the metal-air cell.

Fuel cells of the type that provide a gaseous or liquid fuel, such as hydrogen or methanol, also may benefit from an air manager that can provide air at a gas depolarized electrode while maintaining a needed hydration level in an electrolyte or hydrated membrane ("polymer electrolyte").

Therefore, there has been a need in the art for an air manager incorporating an air moving device that occupies less of the volume available for battery chemistry, is usable with advanced systems for isolating the air electrodes when power is not being drawn from the metal-air cell, is quiet, needs relatively simple controls, consumes power at a relatively low rate, and provides similar advantages for fuel cells. There is a further need for a control means for the air

manager that operates the air manager when necessary during high current draw modes and causes the air manager not to operate during low current draw modes.

Summary of the Invention

The present invention seeks to provide an improved gas moving device for gas depolarized cells that occupies a minimal amount of the volume available for other cell components, is usable with advanced systems for isolating the air electrodes when power is not being drawn from the cell, requires either simple or no control logic circuitry, is quiet, and consumes power at a relatively low rate.

In accordance with one aspect of the invention, this object is accomplished by placing the cell or battery of cells in a casing with at least one ventilation passageway extending from the gas electrodes to an outside gas supply. A resilient diaphragm is placed within the casing and caused to reciprocate, moving in one direction by an electrically induced force an electromagnetic field and in the opposite direction by the resiliency of the diaphragm. The movement of the diaphragm causes gas to be exchanged between the interior of the casing adjacent to the gas electrode and exterior of the casing through the ventilation passageway.

In a preferred embodiment, the present invention provides a resilient ferromagnetic diaphragm having two sides. A coil is positioned near the diaphragm in order to attract the resilient ferromagnetic diaphragm when an

electromagnetic field is created by an electrical current passing through the coil. When the electrical current through the coil is switched off, the diaphragm returns to its original position due to the resiliency of the diaphragm. The resilient ferromagnetic diaphragm may be constructed of a resilient diaphragm with a ferromagnetic plate attached to one side or may be formed from a resilient ferromagnetic material.

In another embodiment, the present invention provides a resilient ferromagnetic diaphragm with two sides and a coil positioned near the diaphragm. An electrical circuit with an electrical current source is used to direct an electrical current through the coil. The current through the coil creates an electromagnetic magnetic field which attracts the diaphragm and causes it to move when a predetermined level of electrical current passes through the coil.

The electrical circuit also contains a pair of contacts with one of the contacts connected to the diaphragm. The contacts are closed when the current flow through the coil is less than a predetermined level. However, when the current flow through the coil is greater than a predetermined level, the diaphragm moves. As the diaphragm moves, the contacts are opened, thus breaking the circuit, de-energizing the coil, and allowing the resiliency of the diaphragm to return it to the original position and remaking the circuit. The de-energizing and re-energizing of the coil may be repeated to cause the diaphragm to oscillate. Also, the resilient ferromagnetic diaphragm may be constructed of a resilient diaphragm with a

ferromagnetic plate attached to one side or may be formed from a resilient ferromagnetic material.

In yet another embodiment, the present invention provides an electrically activated diaphragm with two sides. An electrical circuit with an electrical current source is used to direct an electrical current through the electrically activated diaphragm. The current through the electrically activated diaphragm causes the diaphragm to deform when a predetermined level of electrical current passes through it.

The electrical circuit also contains a pair of contacts with one of the contacts connected to the diaphragm. The contacts are closed when the current flow through the electrically activated diaphragm is less than a predetermined level. However, when the current flow through the electrically activated diaphragm is greater than a predetermined level, the diaphragm deforms. As the diaphragm deforms, the contacts are opened, thus breaking the circuit, and allowing the diaphragm to return it to the original position and remaking the circuit. The de-energizing and re-energizing of the diaphragm may be repeated to cause the diaphragm to oscillate. Also, the electrically activated diaphragm may be constructed of a piezoelectric or EAPS material, or a resilient diaphragm with a strip of piezoelectric material attached to one side

Another aspect of the invention is a method for moving air in gas depolarized cell or battery of cells by encasing the cell or battery of cells in a body having at least one ventilation passageway and reciprocating a resilient diaphragm

contained in the body in one direction with an electromagnetic field and in the other direction by the resiliency of the diaphragm. By reciprocating the diaphragm, air adjacent to the air electrode is exchanged between the interior and exterior of the body. The gas depolarized cell may be either a metal-air cell or a fuel cell of the type that provide a gaseous or liquid fuel, such as hydrogen or methanol.

In a preferred embodiment, the resilient diaphragm is manipulated by positioning a coil near the diaphragm and moving the diaphragm when an electromagnetic field is created by an electrical current passing through the coil. When the electrical current through the coil is switched off, the diaphragm returns to its original position due to the resiliency of the diaphragm.

In another embodiment the manipulation of the diaphragm is controlled by positioning a coil in proximity to the resilient ferromagnetic diaphragm; providing an electrical circuit having an electrical current source; and directing electrical current from the electrical current source through the coil to create an electromagnetic magnetic field to attract the diaphragm and cause it to move when a predetermined level of electrical current passes through the coil. Next in this method the diaphragm is manipulated by providing a pair of contacts with one of the contacts connected to the diaphragm and closed when current flow through the coil is less than a predetermined level; and moving the diaphragm when the presence of current flow through the coil is greater than a predetermined level. When the diaphragm moves, the contacts open thus breaking the circuit, de-

energizing the coil, and allowing the resiliency of the diaphragm to return it to the original position.

The electrical circuit may be reestablished when the contacts are closed after the diaphragm has returned to its original position. When this is done, the electromagnetic magnetic field is recreated and attracts the diaphragm, thus causing the oscillation of the diaphragm while the electrical current available to the coil is greater than a predetermined level.

Another aspect of the invention is an gas mover system for an gas depolarized power supply associated with a load having at least two modes of operation drawing different levels of current from the power supply. A casing having at least one ventilation passageway is utilized to contain one or more cells. The gas may be, for example, air containing oxygen. An air mover is positioned to move air from the exterior to the interior of the casing adjacent to an air electrode of the cell and from the interior adjacent to an air electrode of the cell to the exterior of the casing. The passageway permits a predetermined low flow rate of air from the exterior to the interior of the casing adjacent to an air electrode of the cell during a low current draw mode of operation while the air mover is inoperative. The air mover, however, becomes operative responsive to the initiation of a high current draw mode of operation in a preferred embodiment. In a preferred embodiment, a fan or a resilient reciprocating diaphragm may be used as the air mover and may be powered by the power supply.

The operation of the air mover may be determined by a controller which monitors the load on the power supply. This controller can determine if the load on the power supply corresponds to the high current draw mode of operation and operate the air mover if this condition is found. Also, the controller may be a current divider circuit designed to restrict current to an electric air pump to a magnitude sufficient not to operate the air pump during the low current draw mode and yet direct a magnitude of current to the air pump sufficient to operate during the high current draw mode. Such a circuit can operate on the breaking and re-making principle described above.

This system may be used, for example in a cellular telephone environment. The low current draw mode of the system can correspond to the stand-by mode of a cellular telephone and the high current draw mode of operation can correspond to the transmit/receive mode.

Another aspect of the invention is a method of admitting air to an gas depolarized power supply associated with a load having at least two modes of operation drawing different levels of current from the power supply.

In a preferred embodiment, this is accomplished by enclosing the power supply in a casing with at least one ventilation passageway extending through the casing; initiating the operation of an air mover responsive to the initiation of a high current draw mode of operation of the load on the power supply; and terminating the operation of the air mover during a low current draw mode of operation of the

load. The ventilation passageway permits a predetermined low flow rate of air from the exterior to the interior of the casing while the air mover is inoperative.

The operation of the air mover may be determined by monitoring the load on the power supply; determining if the load corresponds to the high current draw mode of operation; and operating the air mover if the load corresponds to the high current draw mode of operation. Also, an electric air mover may be employed by restricting current to the electric air pump to a magnitude sufficient not to operate during the low current draw mode of operation and directing a magnitude of current to the electric air pump sufficient to operate during the high current draw mode of operation.

In addition, this method may be employed in a cellular telephone environment by utilizing the low current draw mode of operation during the stand-by mode of a cellular telephone and utilizing the high current draw mode of operation during the transmit/receive mode of the cellular telephone.

Yet another aspect of the invention is an air mover system for an gas depolarized cell or battery of cells where the cell or battery of cells is to provide energy for an electrical device. A casing removable from the electrical device is utilized to contain the cell or battery of cells. The casing contains at least one ventilation passageway extending through the casing that mates with the electronic device. A resilient diaphragm is placed within the electronic device and caused to reciprocate, moving in one direction by the force of an electromagnetic field and in the opposite direction by the resiliency of the diaphragm. The movement of the

diaphragm causes air to be exchanged through the ventilation passageway thus moving air between the interior of the casing adjacent to the air electrode and exterior of the casing.

Other objects, features, and advantages of the present invention will become apparent upon reading the following description of exemplary embodiments, when taken in conjunction with the drawings and the claims.

Brief Description of the Drawings

FIG. 1 is a diagrammatic axial cross-sectional view of a cylindrical battery according to a preferred embodiment of the present invention.

FIG. 2 is a graphical representation of the dual mode feature of the present innovation.

FIG. 3a and FIG 3b are schematic diagrams of the operation of the diaphragm air moving system of the present invention.

FIG 4. is a diagrammatic axial cross-sectional view of a battery according to a second embodiment of the present invention.

FIG 5. is a diagrammatic axial view of a battery according to a third embodiment of the present invention.

FIG. 6 is a schematic diagrams of the operation of the diaphragm air moving system of the present invention utilizing a piezoelectric diaphragm.

Detailed Description

The invention may be embodied in a metal-air battery or other type of fuel cell. It is well understood that many types of electrical devices may be powered by a metal-air battery. The cells of the metal-air battery may be similar to those disclosed in commonly owned Serial No. 08/299,997 or in commonly owned U.S. Patent Nos. 5,356,729 or 5,641,588 or 5,569,551, which are incorporated herein by reference. The metal-air battery may include one or more metal-air cells enclosed within a casing. Although the use of the invention with specific types of metal-air cells is disclosed, this invention should be understood as being applicable to any type of metal-air cell, whether primary or secondary, and to other types of fuel cells.

An Exemplary Operating Environment

Referring now in more detail to the drawings, in which like numerals refer to like parts throughout the several views. FIG. 1 is a preferred embodiment of the present invention illustrating a cylindrical battery **100** with a diaphragm air moving system **102** between an upper axial air chamber **104a** and a lower axial air chamber **104b.** The diaphragm air moving system **102** and a metal-air cell **106** are enclosed within a conductive cylindrical casing **108**. The metal-air cell **106** is composed of an anode material **110** in contact with the casing **108**, and a cylindrical air cathode **112** with a separator **113** between the anode material **110** and the air cathode **112**.

The air cathode **112** is electrically isolated from the casing **108** by annular cathode insulators **114**. In the figures, the diameter of the chambers **104a** and **104b** is exaggerated to show detail. In practice, the diameter is minimized.

One side of the air cathodes **112** faces the upper and lower axial air chambers **104a** and **104b**. The opposing side of the air cathode **112** faces the separator **113** which in turn faces the anode material **110**. A diaphragm air moving system **102** is positioned in the casing **108** between an upper axial air chamber **104a** and a lower axial air chamber **104b**. The upper axial air chamber **104a** and a lower axial air chamber **104b** together provide an interior air plenum. Arrows **115, 116, 118,** and **125** represent a typical circulation of air or other gaseous oxygen source into, within, and out of the casing **108** to provide reactant air flow to the air cathodes **112** as a result of operation of the air moving system or in a manner described below.

The casing **108** isolates the metal-air cell **106** from the ambient air with the exception of a plurality of ventilation openings **128** and **130**. The casing preferably is a conductive metal can. Alternatively, the casing may be made of plastic, and the cell may be provided with an anode current collector and an anode terminal extending to the exterior of the casing. Preferably, upper and lower ventilation openings **130** and **128** permit the ambient air to communicate with the upper and lower axial air chambers **104a** and **104b** respectively. Both the upper axial air chamber **104a** and the lower axial air chamber **104b** must have at least one ventilation open per passageway. However the number of ventilation openings **128**

and **130** is not as important as the aggregate size of the ventilation openings **128** and **130** in connection with their shape. The lower ventilation opening **128** through the casing **108** is located on bottom of the battery **100**. A lower diffusion isolation tube **132** connects to the lower ventilation opening **128** and extends from the lower ventilation opening **128** into the lower axial air chamber **104b** of the battery **100**. The upper ventilation opening **130** through the casing **108** is located at the top of the battery **100**. An upper diffusion isolation tube **136** connects to the upper ventilation opening **130**, and extends from the casing **108** into the upper axial air chamber **104a** of the battery **100**.

As described previously, the size, number, shape, or arrangement of the lower diffusion isolation tube **132** corresponding to the lower ventilation opening **128** and the upper diffusion isolation tube **136** corresponding to upper ventilation opening **130** may be selected to further optimize the air flow to the metal-air cell **106**. When taken together, the lower ventilation opening **128** and the upper ventilation opening **130** are of sufficient size to admit and expel a quantity of air into and out of the casing **108** dependent upon the metal-air cell's **106** power requirements. A detailed discussion of the isolation function of the diffusion isolation tubes is provided in the section on ventilation openings below.

The diaphragm air moving system **102** provides an increased air flow into and out of the upper and lower axial air chambers **104a** and **104b** adjacent to the air cathode **112.** The operation of the diaphragm air moving system **102** occurs during certain high current draw modes of operation of the metal-air cell **106** and ceases

during low current draw modes of operation. A detailed discussion of these two modes of operation in conjunction with the initiation of the air moving system **102** is provided below.

A ferromagnetic rolling diaphragm **150** is placed across the interior of the battery **100** perpendicular to air cathode **112,** and between the upper axial air chamber **104a** and the lower axial air chamber **104b**. The circular ferromagnetic rolling diaphragm **150** is attached to the air cathode **112** through an annular diaphragm insulator **155,** thus electrically isolating the ferromagnetic rolling diaphragm **150** from the air cathode **112** at the point where it fastens to the air cathode **112**. The ferromagnetic rolling diaphragm **150** may be made of a resilient material diaphragm with a ferromagnetic plate attached or may be formed of a resilient ferromagnetic material. The diaphragm may be made of various flexible materials including a thermoplastic elastomer (TPE) such as Santoprene® thermoplastic rubber available from Advanced Elastomer Systems.

In addition to the ferromagnetic rolling diaphragm **150,** a perforated circular plate **160** is placed across the interior of the battery **100.** The perforated plate **160** is located within the lower axial air chamber **104b**, perpendicular to air cathode **112,** and parallel to the ferromagnetic rolling diaphragm **150**. The perforated plate **160** is not insulated from the air cathode **112**, but rather is conductive and is connected to a cylindrical cathode current collector **111** placed longitudinally within the air cathode **112**. The perforations in the perforated plate **160** allow air

flow **116** to flow through the perforated plate and into and out of the lower axial air chamber **104b.**

In order to provide a source for an electromagnetic field, a coil **165** is positioned between the ferromagnetic rolling diaphragm **150** and the perforated plate **160**. One end of the coil **165** is electrically connected to the ferromagnetic diaphragm **150** through a flexible coil lead **170**. The opposite end of the coil is electrically connected to the perforated plate **160**. The movement of the ferromagnetic diaphragm **150** and the need for the flexible coil lead **170** is discussed below.

At the top of the battery **100** is located a terminal projection **138** which is insulated from the conductive cylindrical casing **108** through the use of a terminal projection insulator **140**. A contact lead **180** provides a connection between the terminal projection **138** and contacts **185** positioned to make electrical contact with the diaphragm **150** when the diaphragm is in a relaxed, upper position as shown in Figs. **1** and **3a**. A resistor **175** is placed between the cathode current collector **111** and the contact lead **180**. When a load **190** is connected to the battery **100** between the terminal projection **138** and the conductive cylindrical casing **108**, a load current (I_L) **192** is drawn from the metal-air cell **106.** When the contacts **185** are closed, (that is, contacting the diaphragm **150** in its upper position) the load current (I_L) **192** is drawn through two parallel paths comprising a resistor path corresponding to a resistor current (I_R) **194** and a coil path corresponding to a coil current (I_C) **196**. However, if the contacts **185** are open, then there is no current in

the coil path. Both currents originate from the cathode current collector **111** and sum together at the contact lead **180** to equal load current (I_L) **192**.

The resistor current (I_R) **194** originates from the cathode current collector **111**, continues through the resistor **175** and then to contact lead **180**. The coil current (I_C) **196** also originates with the cathode current collector **111**, but continues through the perforated plate **160**, through coil **165** and then through the flexible coil lead **170**. From the flexible coil lead **170**, the coil current (I_C) **196** continues through the ferromagnetic rolling diaphragm **150**. With the contacts **185** closed, the coil current (I_C) **196** continues through the contacts **185** and then to the contact lead **180**. As stated previously, the resistor current (I_R) **194** and the coil current (I_C) **196** sum together in the contact lead **180** to create the load current (I_L) **192**. The load current (I_L) **192** continues out of the battery **100** from the contact lead **180**, through the terminal projection **138** and into the load **190**.

<u>Dual Mode Feature</u>

During the operation of the metal-air cell **106**, the load current (I_L) **192** will vary depending upon the demand placed upon the metal-air cell **106** by the load **190**. In some electrical devices, such as cellular telephones, the magnitude of the load current (I_L)**192** can be characterized as having two levels, herein described as a low current draw mode and a high current draw mode.

During the low current draw mode, the upper diffusion isolation tube **136** along with the lower diffusion isolation tube **132** permit a predetermined low flow rate of air into the upper and lower axial air chambers **104a** and **104b**. This

predetermined low flow rate of air is sufficient to service the needs of the air cathode **112** at a level which enables the battery **100** to provide energy to the load **190**, when the load **190** demands a load current **192** corresponding to a low current draw mode. Since the upper diffusion isolation tube **136** along with the lower diffusion isolation tube **132** are sufficient to provide air to the air cathode **112**, the operation of the diaphragm air moving system **102** is not necessary during the low current draw mode.

During the high current draw mode, however, the upper diffusion isolation tube **136** along with the lower diffusion isolation tube **132** are not sufficient alone to service the needs of the air cathode **112**. In order to provide the necessary flow rate of air sufficient to service the needs of the air cathode **112** during the high current draw mode, the diaphragm air moving system **102** must be engaged.

FIG 2 illustrates the dual mode feature of the battery **100** and the initiation of the diaphragm air mover **102**. The graph shows that the load current **192** remains at a magnitude I_{LOW} for a time between t=0 and t=T. At time t=T, the load current **192** rapidly moves from $I_L=I_{LOW}$ to $I_L=I_{HIGH}$. As the load current **192** makes this transition, it passes a magnitude I_{SWITCH} that is the level of load current **192** at which the operation of the diaphragm air moving system **102** is initiated. I_{HIGH} is of a greater magnitude than I_{SWITCH}. For time t>T the diaphragm air moving system **102** operates since the load current **192** is greater than I_{SWITCH}.

For an example of the operation of the dual mode feature, consider a cellular telephone. When a cellular telephone is in the stand-by mode, the energy

consumed is minimized. The load current **192** (I_L) during the stand-by mode corresponds to the I_{LOW} level illustrated in FIG.2. At a point in time t=T, the cellular telephone either receives a call or a user places a call using the cellular telephone. At this point, the energy need begins at a low current draw mode corresponding to the stand-by mode and transitions to a high current draw mode corresponding to the transmit mode of the cellular telephone. During this transition, the load current **192** (I_L) passes through a level I_{SWITCH} which is the level of load current **192** at which the operation of the diaphragm air moving system **102** is initiated. Therefore, the diaphragm air moving system **102** is engaged. to provide the necessary flow rate of air sufficient to service the needs of the air cathode **112** during the transmit mode of the cellular telephone.

Operation of the Air Mover

Referring back to FIG. 1, if the load **190** is less than a specified magnitude corresponding to the low current draw mode, a resulting coil current (I_C) **196** will be drawn which is less than a predetermined level and will not create sufficient electromagnetic force to move the diaphragm **150** and thus will not cause the oscillation of the ferromagnetic rolling diaphragm **150**. If, however, the load **190** is greater than a specified magnitude corresponding to a high current draw mode, a resulting coil current (I_C) **196** will be drawn which is greater than a predetermined level and sufficient to oscillate the ferromagnetic rolling diaphragm **150**. The predetermined level of coil current (I_C) **196** capable of causing the oscillation of the ferromagnetic rolling diaphragm **150,** and below which the ferromagnetic rolling

diaphragm **150,** does not oscillate, can be determined by the size of resistor **175** in coordination with load **190**.

For example, the size of the coil **165** can be determined by the coil size necessary to create a magnetic field large enough to sufficiently pull the ferromagnetic rolling diaphragm **150**. Next, given the magnitude of load current (I_L) **192** at which the battery **100** needs the increased air flow, the resistor **175** is sized in order to cause a sufficient coil current (I_C) **196** for the high current draw mode. The coil current (I_C) **196** for the high current draw mode must be of sufficient magnitude to create a magnetic field large enough to sufficiently pull the ferromagnetic rolling diaphragm **150.** However, if the load current (I_L) **192** falls sufficiently below this level, the corresponding coil current (I_C) **196** must not be of sufficient magnitude to create a magnetic field large enough to sufficiently pull the ferromagnetic rolling diaphragm **150.**

Turning now to FIGs. 3a and 3b which illustrate the oscillation of the ferromagnetic rolling diaphragm **150** and the operation of the diaphragm air moving system **102**. In FIG. 3a, load current (I_L) **192** is drawn from the cell **306** when load **190** is connected to battery **100**. The cell **306** may be comprised of an gas depolarized electrochemical power source, such as a metal-air battery, or may be comprised of fuel cells of the type that are supplied with reactive gas such as hydrogen or methanol by an active air moving device. Load current (I_L) **192** divides at node **210** into the coil current (I_C) **196** and the resistor current (I_R) **194**. Once the two currents pass through their respective parallel paths, they sum

together at node **220** to a magnitude equal to load current (I_L) **192**. After node **220**, the load current (I_L) **192** continues to serve load **190** and then returns to the cell **306**, thus completing the electrical circuit.

During a high current draw mode, as discussed above, it is necessary to engage the diaphragm air moving system **102** and cause the ferromagnetic rolling diaphragm **150** to oscillate. In order to accomplish this, the coil current (I_C) **196** must be of a magnitude to cause the coil **165** to create a magnetic field great enough to attract the ferromagnetic rolling diaphragm **150**. Given the high current draw mode, the ferromagnetic rolling diaphragm **150** is pulled toward the coil **165**, and the contacts **185** open. The flexible coil lead **170** allows the coil **165** to remain electrically connected to the ferromagnetic rolling diaphragm **150** during movement. FIG. 3b is an illustration of the system with the contacts **185** open. After the contacts open, the coil current (I_C) **196** will go to zero, though not instantaneously. When the coil current (I_C) **196** is at zero, the magnetic field attracting the ferromagnetic rolling diaphragm **150** will cease. With the magnetic field no longer present, the resiliency of the ferromagnetic rolling diaphragm **150** will return the ferromagnetic rolling diaphragm **150** to its original position.

When the ferromagnetic rolling diaphragm **150** returns to its original position, the contacts **185** which were open will now re-close. With the contacts **185** now in the closed position, the coil current (I_C) **196** will be reestablished thus reestablishing the magnetic field and once again attracting the ferromagnetic rolling diaphragm **150**. This process will repeat and cause the ferromagnetic

rolling diaphragm **150** to oscillate as long as the coil current (I_C) **196** is available to the coil **165** and is greater or equal to a predetermined level sufficient to attract the ferromagnetic rolling diaphragm **150**. In addition, the coil and resistor can be tuned to cause the ferromagnetic rolling diaphragm **150** to oscillate at a frequency not within the audible range of the human ear. This will allow the air mover to operate quietly with respect to human detection.

It should be understood that the air moving system of the present invention can be applied to an electrical device having a single mode of operation. In this case, the low current draw mode occurs when the device is "off" and draws no current.

Second Embodiment of the Present Invention

Turning now to FIG. 4 illustrating a second embodiment of the present invention comprising a battery **400** with a diaphragm air moving system **402** between an upper chamber **404a** and a lower chamber **404b.** The diaphragm air moving system **402** and a metal-air battery of cells **406** are enclosed within a prismatic casing **408**. The metal-air battery of cells **406** having a cathode terminal **412** and an anode terminal **414,** includes a plurality of metal-air cells **410**. The diaphragm air moving system **402** is positioned in the casing **408** between the upper chamber **404a** and the lower chamber **404b**.

The casing **408** isolates the metal-air battery of cells **406** from the ambient air with the exception of a ventilation opening **428**. The casing preferably

is a plastic material, or a metal can insulated from the interior components. Preferably, the ventilation opening **428** permits the ambient air to communicate with the lower chamber **404b**. The lower chamber **404b** must have at least one ventilation opening **428**; the number of ventilation openings is not as important as the aggregate size of the ventilation openings in connection with their shape. The lower ventilation opening **428** is of sufficient size to admit and expel a quantity of air into and out of the casing **408** dependent upon the metal-air battery of cell's **406** power requirements.

The ventilation opening **428** through the casing **408** is located on bottom of the battery **400**. A diffusion isolation tube **432** connects to the ventilation opening **428** and extends from the lower ventilation opening **428** into the lower chamber **404b** of the battery **400**

The diaphragm air moving system **402** provides an increased air flow into and out of the lower chamber **404b** adjacent to the air cathodes of the metal-air cells **410.** The operation of the diaphragm air moving system **402** occurs during certain high current draw modes of operation of the metal-air battery of cells **406** and ceases during low current draw modes of operation. A detailed discussion of these two modes of operation has been discussed previously.

A conductive ferromagnetic rolling diaphragm **150** is placed across the interior of the battery **400** above the lower chamber **404b**. The ferromagnetic rolling diaphragm **150** is attached to the casing **408**. The diaphragm may be formed in a rectangular shape, or may be a circular or ellipse mounted in a

rectangular frame. In addition to the ferromagnetic rolling diaphragm **150,** a perforated plate **160** is placed across the interior of the battery **400.** The perforated plate **160** is located within the lower chamber **404b** and parallel to the ferromagnetic rolling diaphragm **150**. The perforated plate **160** and the ferromagnetic rolling diaphragm **150** are not electrically connected to the casing **408**. The perforations in the perforated plate **160** allow air to flow through the perforated plate and into and out of the lower chamber **404b.**

In order to provide a source for an electromagnetic field, a coil **165** is positioned between the ferromagnetic rolling diaphragm **150** and the perforated plate **160**. One end of the coil **165** is electrically connected to the ferromagnetic diaphragm **150** through a flexible coil lead **170**. The opposite end of the coil is electrically connected to the perforated plate **160**.

On the exterior of the battery **400** are located a cathode terminal projection **415** and an anode terminal projection **420** which are insulated form the casing **408**. When a load **190** is connected to the battery **400** between the terminal projections **415** and **420**, a load current (I_L) **192** is drawn from the metal-air battery of cells **406**. The load current (I_L) **192** is drawn through two parallel paths comprising a resistor path corresponding to a resistor current (I_R) **194** and a coil path corresponding to a coil current (I_C) **196**. Both currents originate from the cathode terminal **412** and sum together at the cathode terminal projection **415** to equal load current (I_L) **192**.

The resistor current (I_R) **194** originates from the cathode terminal **412**, continues through the resistor **175** and then to the cathode terminal projection **415**. The coil current (I_C) **196** also originates with the cathode terminal **412**, but continues through the perforated plate **160**, through coil **165** and then through the flexible coil lead **170**. From the flexible coil lead **170**, the coil current (I_C) **196** continues through the ferromagnetic rolling diaphragm **150**. If the contacts **185** are closed, the coil current (I_C) **196** continues through the contacts **185** and then to the contact lead **180**. As stated previously, the resistor current (I_R) **194** and the coil current (I_C) **196** sum together in the cathode terminal projection **415** to create the load current (I_L) **192**. The load current (I_L) **192** continues out of the battery **400** from the cathode terminal projection **415**, and into the load **190**. The diaphragm air moving system **402** operates in similar fashion to the system discussed in the sections on the operation of the air mover and the dual mode feature above.

Third Embodiment of the Present Invention

FIG. 5 illustrates a third embodiment of the present invention comprising an electrical device **500**. In this embodiment an air moving system **502** is contained within the electrical device **500** and not within a metal-air battery. The electrical device casing **508** defines a load chamber **501** for the electrical components of the device and a diaphragm air moving system **502** which comprises an upper chamber **504a** and a lower chamber **504b** separated by a diaphragm **150.** The chamber **504b**

is atmospherically isolated from the other chambers. The diaphragm air moving system **502** is enclosed within the electrical device casing **508**.

A metal-air battery **506** is contained in a cylindrical or prismatic battery casing **509** which is mateably received within a battery chamber **511** defined in to the electrical device casing **508** adjacent to the lower air mover chamber **504b**. The battery casing **509** includes one or more metal-air cells **510**, and defines a projection **513** that is tightly but moveably received within a mating opening **515** of the chamber **504b** when the battery casing **509** is inserted into the chamber **511**. The projection **513** includes a battery cathode terminal **512** and a battery anode terminal **514** positioned and spaced apart on the sides of the projection. As battery casing **509** slides completely into electrical device casing **508**, the battery cathode terminal **512** makes electrical contact with an air mover cathode terminal **516** and the battery anode terminal **514** makes electrical contact with an air mover cathode terminal **518** positioned within the opening **515**. The projection **519** defines an isolation passageway **514** into the battery housing **509**.

Once the battery casing **509** has been completely mated with casing **508,** the cells of the metal-air battery **506** are isolated from the ambient air with the exception of a ventilation opening **528**. However, the seal between the projection **513** and the opening **515** need not be air tight. The casings **508** and **509** are preferably made of a plastic material, or are made of metal insulated from the interior components. The battery casing **509** optionally may be held in chamber **511** by a door, latch, detent, or the like (not shown). The ventilation opening **528**

permits the ambient air to communicate with a battery chamber **504c**. The ventilation opening **528** through the battery casing **509** is located on on a surface exposed to the ambient air. A diffusion isolation tube **532** connects to the ventilation opening **528** and extends from the lower ventilation opening **528** into the batter chamber **504c** of the battery casing **509.** The battery chamber **504c** must have at least one ventilation opening **528**; and associated isolation passageway **532** the number of ventilation openings is not as important as the aggregate size of the ventilation openings in connection with their shape. The lower ventilation opening **528** and associated isolation tube 532 are of sufficient size to admit and expel a quantity of air into and out of the casing **509** dependent upon the metal-air battery of cell's **506** power requirements. Air is caused to communicate between lower air mover chamber **504b** and the battery chamber **504c** through the passageway **519** when the air mover is operating.

The diaphragm air moving system **502** provides an increased air flow into and out of the battery chamber **504c** adjacent to the air cathodes of the metal-air cells **510.** The operation of the diaphragm air moving system **502** occurs during certain high current draw modes of operation of the metal-air battery of cells **506** and ceases during low current draw modes of operation. These two modes of operation have been discussed previously.

The conductive ferromagnetic rolling diaphragm **150** is placed within the electrical device **500** to separate the upper and lower chambers **504a** and **504b**. The ferromagnetic rolling diaphragm **150** is attached to the casing **508**. If the

chambers are prismatic, the diaphragm may be formed in a rectangular shape, or may be a circular or ellipse mounted in a rectangular frame. If the chambers are cylindrical, the diaphragm is preferably circular. The ferromagnetic rolling diaphragm **150** is not electrically connected to the casing **508**. A vent **529** equalizes pressure in the upper chamber **504a**. The vent **529** can lead either to the outside of the device casing **508** as shown, or to the load chamber **501** of the casing **508**.

In order to provide a source for an electromagnetic field, a coil **165** is positioned in proximity to the ferromagnetic rolling diaphragm **150**. One end of the coil **165** is electrically connected to the ferromagnetic diaphragm **150** through a flexible coil lead **170**. The opposite end of the coil is electrically connected to the air mover cathode terminal **516**. It should be understood that the coil can be placed on either side of the diaphragm, in this as well as previous embodiments.

Through the wall of the lower chamber **504b** are located a cathode terminal projection **520** and an anode terminal projection **522** which are insulated from the casing **508**. When a load **190** is connected between the terminal projections **520** and **522**, a load current (I_L) **192** is drawn from the metal-air battery of cells **506**. The load current (I_L) **192** is drawn through two parallel paths comprising a resistor path corresponding to a resistor current (I_R) **194** and a coil path corresponding to a coil current (I_C) **196**. Both currents originate from the battery cathode terminal **512** and sum together at the cathode terminal projection **520** to equal load current (I_L) **192**.

The resistor current (I_R) **194** originates from the battery cathode terminal **512**, continues through the resistor **175** and then to the cathode terminal projection **520**. The coil current (I_C) **196** also originates with the cathode terminal **512**, but continues through the coil **165** and then through the flexible coil lead **170**. From the flexible coil lead **170**, the coil current (I_C) **196** continues through the ferromagnetic rolling diaphragm **150**. If the contacts **185** are closed, the coil current (I_C) **196** continues through the contacts **185** and then to the contact lead **180**. As stated previously, the resistor current (I_R) **194** and the coil current (I_C) **196** sum together in the cathode terminal projection **520** to create the load current (I_L) **192**. The load current (I_L) **192** continues out of the the cathode terminal projection **520** and into the load **190**. The diaphragm air moving system **502** operates in similar fashion to the system discussed in the sections on the operation of the air mover and the dual mode feature above.

<u>Fourth Embodiment of the Present Invention</u>

FIG. 6 illustrates an alternative to the diaphragm **150**, namely, a electrically activated diaphragm **650,** and the operation of the diaphragm **650** in the air moving system **102**. The electrically activated diaphragm **650** can be made of flexible piezoelectric material, electrostatic material, or electroactive polymers (EAPS). Examples of EAPS include bending actuators or ionomers and longitudinal electrostatically driven polymers. Bending actuators or ionomers can include perfluorinated ion exchange membrane platinum composites (IMPC) based on a processed Nafion® film manufactured by DuPont. EAPS can bend, stretch, extend,

or displace in a predetermined direction in response to an applied electrical current or voltage. Those skilled in the art will be familiar with the various methods used to manufacture EAPS into sheets usable as a diaphragm. Furthermore, those skilled in the art will realize that EAPS provide greater response time, lower material density, lower power consumption, improved fatigue characteristics, mass production capabilities, and the lack of poling needed when compared to conventional piezoelectric materials, as well as cost and space savings advantages over other conventional materials.

Referring to Fig. 6, the load current (I_L) **192** is drawn from metal-air cell **106** when load **190** is connected to battery **100**. Load current (I_L) **192** divides at node **210** into the diaphragm current (I_D) **696** and the resistor current (I_R) **194**. Once the two currents pass through their respective parallel paths, they sum together at node **220** to a magnitude equal to load current (I_L) **192**. After node **220**, the load current (I_L) **192** continues to serve load **190** and then returns to the metal-air cell **106**, thus completing the electrical circuit.

During a high current draw mode, as discussed above, it is necessary to engage the diaphragm air moving system **102** and cause the electrically activated diaphragm **650** to oscillate. In order to accomplish this, the diaphragm current (I_D) **696** must be of a magnitude to cause the electrically activated diaphragm **650** to deform. In the presence of this high current draw mode, the electrically activated diaphragm **650** is deformed in such a way as to pull the electrically activated diaphragm **650** away from the contacts **185** into a position shown in dashed lines as

650', thus causing the contacts to open. The flexible diaphragm lead **670** allows the electrically activated diaphragm **650** to remain electrically connected to the node **210** during movement of the electrically activated diaphragm **650.** After the contacts **185** open, the diaphragm current (I_D) **696** will go to zero. When the diaphragm current (I_D) **696** is at zero, the electric current causing the diaphragm to deform will cease. With this current no longer present, the electrically activated diaphragm **650** will return to its original position.

When the electrically activated diaphragm **650** returns to its original position, the contacts **185** will now re-close. With the contacts **185** now in the closed position, the diaphragm current (I_D) **696** will be reestablished thus reestablishing the current through the electrically activated diaphragm **650** and once again deforming the electrically activated diaphragm **650**. This process will repeat and cause the electrically activated diaphragm to oscillate between the solid and dashed line positions as long as the diaphragm current (I_D) **696** is available to the electrically activated diaphragm **650** and is greater or equal to a predetermined level sufficient to deform the electrically activated diaphragm **650**. In addition, the circuit can be tuned to cause the electrically activated diaphragm **650** to oscillate at a frequency not within the audible range of the human ear. This will allow the air mover to operate quietly with respect to human detection.

Diaphragm Activation Current

It should be understood from the foregoing that the air moving system of the present invention can be applied to an electrical device having a single mode of operation. In this case, the device either is "off" and draws no current, or is in a high current draw mode. Referring to Fig. 3a, the coil current I_C **196** needed to oscillate the conductive ferromagnetic diaphragm **150** may typically be less than or equal to 50 mA, and preferably about 20 mA. The voltage across the coil necessary for oscillation is approximately 1 V when taken in conjunction with the aforementioned currents, but may vary depending on the characteristics of the coil.

Referring to Fig. 6, the minimum diaphragm current I_D **696** needed to oscillate an electrically activated diaphragm **650** when the diaphragm is made of a piezoelectric material may typically be less than or equal to about 1 mA, and preferably about 0.1 to 0.2 mA. Similarly, the minimum current I_D needed to oscillate an EAPS type diaphragm may typically fall within a range between about 50 mA and 1 mA , and preferably within a range between about 20 mA and 0.1 mA. The voltage across these types diaphragms necessary for oscillation is approximately 5 V when taken in conjunction with the aforementioned currents, again depending on the characteristics of the diaphragm.

In the case of a battery-powered device having two modes of operation as described above, the isolation passageways are sized to allow a selected level of air flow when the air mover is off. For example, consider a cellular telephone application where the stand-by mode draws approximately 5 mA

and the transmit mode draws as much as 1A. In the embodiment utilizing the coil-actuated conductive ferromagnetic diaphragm, the threshold current necessary to oscillate the diaphragm can be approximately 20 mA. In this case, the diffusion tubes should be designed to allow enough air into the air chamber to maintain approximately a 10% O_2 content within the air chamber. In order to maintain this O_2 content with two diffusion tubes, the diffusion tubes should be designed to have a cross sectional area to length ratio of approximately 0.03. Of course, consistent with standard gas diffusion laws, the ratio for each tube would change if only one diffusion tube is used or if more than one cell is being isolated by the tube or tubes. When the cellular telephone is in the stand-by mode, the diffusion tubes supply sufficient oxygen without an air mover. However, when the cellular telephone transitions from the stand-by mode to the transmit mode, the current draw passes through the threshold and the air mover becomes operational.

Ventilation Openings

In the case of the single mode embodiment, in which the electrically powered device is either on or off, the isolating passageways **132**, **136**, **432**, **532**, and **519** described above, are preferably constructed and arranged to allow a sufficient amount of airflow therethrough while the air moving device is operating so that a sufficient output current, typically at least 50 ma, and preferably at least 130 ma can be obtained from the metal-air cells. In addition, the isolating passageways are preferably constructed to limit the airflow and diffusion

therethrough to a level consistent with the needs of the battery-powered product to which the cells are connected. In the simplest case, when the device has only a single "on" mode, the isolation passageway is sized such that the drain current that the metal-air cells are capable of providing to a load while the air moving device is not forcing airflow through the isolating passageways is smaller than the output current by a factor of about 50 or greater. In addition, the isolating passageways are preferably constructed to provide an “isolation ratio” of more than 50 to 1.

The “isolation ratio” is the ratio of the rate of water loss or gain by a cell while its oxygen electrodes are fully exposed to the ambient air, as compared to the rate of the water loss or gain of the cell while its oxygen electrodes are isolated from the ambient air, except through one or more limited openings. For example, given identical metal-air cells having electrolyte solutions of approximately thirty-five percent (35%) KOH in water, an internal relative humidity of approximately fifty percent (50%), the ambient air having a relative humidity of approximately ten percent (10%), and no fan-forced circulation, the water loss from a cell having an oxygen electrode fully exposed to the ambient air should be more than 100 times greater than the water loss from a cell having an oxygen electrode that is isolated from the ambient air, except through one or more isolating passageways of the type described above. In this example, an isolation ratio of more than 100 to 1 should be obtained.

More specifically, each of the isolating passageways preferably has a width that is generally perpendicular to the direction of flow therethrough, and a length

that is generally parallel to the direction of flow therethrough. The length and the width are selected to substantially eliminate airflow and diffusion through the isolating passageways while the air moving device is not forcing airflow through the isolating passageways. The length is greater than the width, and more preferably the length is greater than about twice the width. The use of larger ratios between length and width are preferred. Depending upon the nature of the metal-air cells, the ratio can be more than 200 to 1. However, the preferred ratio of length to width is about 10 to 1.

The isolating passageways could form only a portion of the path air must take between the ambient environment and the oxygen electrodes. Each of the isolating passageways may be defined through the thickness of the battery housing or cell case, but preferably they are in the form of tubes as described above. In either case, the isolating passageways may be cylindrical, and for some applications each can have a length of about 0.3 to 2.5 inches or longer, with about 0.88 to 1.0 inches preferred, and an inside diameter of about 0.03 to 0.3 inches, with about 0.09 to 0.19 inches preferred. The total open area of each isolating passageway for such applications, measured perpendicular to the direction of flow therethrough, is therefore about 0.0007 to 0.5 square inches. In other applications, such as small cylindrical cells, the isolating passageways each can have a length of about 0.1 to 0.3 inches or longer, with about 0.1 to 0.2 inches preferred, and an inside diameter of about 0.01 to 0.05 inches, with about 0.015 inches preferred.

In the case of the dual mode embodiment in which the electrically powered device has a standby mode powered by the cell or cells without operation of the air mover, the diffusion tubes are opened somewhat, to a larger ratio of cross sectional area to length. For this embodiment, the isolation ratio preferably may be as low as about 20:1. In this way, some cell life is compromised in order to provide the dual mode operation of the cells. The needed ratio of cross sectional area to length for each diffusion tube depends on the amount of current desired in the standby mode, the number of tubes, and amount of air cathode area of the one or more cells within a battery housing isolated by the tubes, and can be calculated based on the laws or gas diffusion and the electrochemical reactions at the cathode, known to those skilled in the art. These laws can be used to demonstrate that 107.2 amp-hours can be produced per mole of oxygen in the air admitted through the tubes to the cathode.

The preferred dimensions for a particular application will be related to the geometry of the passageways and the cathode plenums, the particular air mover utilized, and the volume or air needed to operate the cells at a desired level.

The isolating passageways are not necessarily cylindrical, as any cross-sectional shape that provides the desired isolation is suitable. The isolating passageways need not be uniform along their length, so long as at least a portion of each isolating passageway is operative to provided the desired isolation. Further, the isolating passageways may be straight or curved along their length.

In view of the foregoing, it will be appreciated that the invention provides an improved air moving device for metal-air cells that occupies a minimal amount of the volume available for battery chemistry, is usable with advanced systems for isolating the air electrodes when power is not being drawn from the metal air cell, requires either simple or no control logic circuitry, is quiet, and consumes power at a relatively low rate. Further, the system is responsive to a dual level load, detecting the change in the load level and activating the air mover during the high current draw mode and de-activating the air mover during the low current draw mode. It will be understood that the preferred embodiment has been disclosed by way of example, and that other modifications may occur to those skilled in the art without departing from the scope and spirit of the appended claims.